1   **EVALUATION OF MAINTENANCE EFFECTIVENESS**
2   **FOR WSDOT PAVEMENT NETWORK**
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1 **ABSTRACT**

2 Any economical extension of pavement service life has a significant benefit for long-term life-
3 cycle costs. Pavement maintenance activities can substantially extend the pavement service life
4 or keep it from prematurely failing. The simple concept of higher costs due to deferred
5 maintenance becomes more complicated when the objective is quantifying the cost tradeoffs, and
6 selecting among maintenance alternatives. Current budget constraints in Washington State
7 necessitate the development of new strategies with regard to pavement maintenance and
8 preservation. Even if the optimum long-term rehabilitation plan for a particular section of
9 roadway calls for a rehabilitation project, there often are no funds available to program the
10 construction. This situation has resulted in the development of maintenance strategies for the
11 purpose of delaying or avoiding pavement rehabilitation spending. These strategies include: (1)
12 addressing early distress, (2) correcting short distressed sections, (3) maintaining and "holding"
13 sections that are currently due for rehabilitation, and (4) integrating maintenance with
14 rehabilitation strategies. The focus of this paper is to evaluate the effectiveness of different
15 pavement maintenance strategies, and improve the procedures for analyzing maintenance
16 tradeoffs. To illustrate the impacts of the maintenance strategy on a network level, three
17 pavement preservation alternatives are compared, and associated costs are estimated for the
18 Washington State pavement network.

INTRODUCTION

Like all state highway agencies, one of the major tasks of Washington State Department of Transportation (WSDOT) is to preserve the State pavement network (which includes 18,650 lane-miles of state highways, and 2,000 lane miles of ramps and special use lanes). This mission requires managing pavements to the lowest life-cycle cost through the monitoring of performance to determine the optimum time for rehabilitation (*1*). The optimum point for rehabilitation is determined by the Washington State Pavement Management System (WSPMS), which monitors pavement performance indexes related to pavement structure, rutting, and roughness (*2*).

Investment in the preservation of WSDOT's pavement infrastructure has been declining steadily since 1999 with reductions accumulating to one billion dollars during the last 14 years (*3*, *4*). Pavement preservation (rehabilitation and maintenance) funding is projected to continue to decline. Anticipated funds for preserving the pavement network in the next six years are expected to be at less than half the level it was in the early 2000s. Continuing budget shortfalls are developing a backlog of pavement rehabilitation needs that must be addressed. The onset of severe budget constraints has put downward pressure on the pavement performance objectives because funds simply are not available to implement the optimum rehabilitation strategy with the lowest life-cycle cost. The objective function has changed from maximizing performance under budget constraints to minimizing long-term costs under minimum performance constraints.

Maintenance strategies were developed for the purpose of delaying or avoiding pavement rehabilitation spending. In these strategies, preservation funds are being specifically allocated for maintenance activities. An important strategy for WSDOT is the extension of pavement service life through the use of maintenance and minor rehabilitation activities. Any economical extension of pavement service life is a significant benefit to the long-term life-cycle costs.

Maintenance effectiveness depends on how the maintenance activities are related to the pavement performance. It is difficult to quantify the effects since there are many factors (such as weather, traffic loading, pavement materials, structure, rehabilitation/maintenance history, timing of maintenance, and other type of maintenance applied at the same time, etc.) affecting pavement performance. From a statistical view, it is difficult to separate out the confounding effects of these factors and to assign specific cause-effect relationships for different maintenance activities. The concept of higher costs for deferred maintenance becomes more difficult when the objective is quantifying the cost tradeoffs, and selecting among maintenance alternatives.

The focus of this paper is to evaluate the effectiveness of pavement maintenance, and improve the procedures for analyzing maintenance tradeoffs. WSDOT is beginning to implement improved coordination and information sharing between the management of rehabilitation programs and roadway maintenance. In addition, funds originally programmed for pavement rehabilitation have been set aside for strategic maintenance activities, using the concept that strategically applied maintenance will reduce the overall cost of pavement rehabilitation projects.

LONG-TERM MONITORING OF WSDOT PAVEMENT PERFORMANCE

WSDOT is very fortunate to have been one of the early implementers of pavement management system in the 1970s, so it has a substantial experience with long legacy of database system and pavement performance monitoring (*1*, *5*). Among 18,650 lane-miles of mainline highways,

approximately 58 percent of the pavement surfaces are asphalt concrete pavements (ACP), 29 percent are chip seal pavements, and Portland cement concrete pavements (PCCP) makes up 13 percent which is mostly un-doweled jointed plain concrete pavement (JPCP) (*1*). Pavement performance is monitored based on an annual condition survey for each 0.1 mile pavement segment. The survey is performed using an automated pavement condition vehicle on the outside lane (usually the lane in the poorest condition) of all state roads in one direction, and divided roads in both directions. The survey rates the pavement condition for cracking, spalling, patching, roughness, rutting, and faulting for PCCP.

The Washington State Pavement Management System (WSPMS) stores all WSDOT pavement historical performance, road configuration, location, structure, traffic, rehabilitation history and construction contracts. The pavement rehabilitation and maintenance plans are generated based on these data and pavement performance models.

WSDOT Pavement Condition Index

The approach of the WSPMS is not to predict pavement performance using generalized models because of the variability inherent in a statewide pavement network. Instead, the performance of each 0.1 mile pavement section is monitored until the performance data show they are projected to reach the optimum time for rehabilitation. Use of a pavement condition index is a reasonable way to quantify this pavement performance over time. WSDOT uses three condition indexes to monitor pavement performance:

- **Pavement Structural Condition (PSC)** for pavement structure, primarily based on cracking and patching. Faulting is considered for concrete pavement.
- **Pavement Profile Condition (PPC)** for pavement roughness, and
- **Pavement Rutting Condition (PRC)** for pavement rutting (*6*).

These are all quantified on a scale of 100 (no defects) to 0 (complete failure), and the pavement performance is monitored based on tracking the three indexes over time. WSPMS estimates a rehabilitation need when any one of the three indexes reaches a value of 45-50. The time when this rehabilitation need occurs is termed the "Due Year". The index value of 50 was originally justified through a life-cycle cost evaluation of different rehabilitation "trigger" values. This procedure has also been in use for a number of years at WSDOT and historically has been shown to be an effective policy for pavement rehabilitation, namely, the rehabilitation is done early enough to preclude major structural failures. The 0.1 lane-mile sections and their associated rehabilitation needs are then aggregated into larger units, called Preservation Units that are programmed for maintenance or rehabilitation.

Piecewise Approximation

Over the last four years, WSDOT developed a pavement performance model using a piecewise approximation approach to estimate the change in the rate of pavement deterioration over time. The basic concept associated with the piecewise approximation is to divide the entire pavement serviceable life into three or more zones for the different stages of pavement deterioration and the timing of rehabilitation/maintenance. This approach is able to predict the pavement distress

1 progression trends in each individual zone by eliminating the possible impacts from the data in
2 the other zones (7).

3   Using the piecewise approximation, six distress condition zones were defined for
4 preservation timing. They are: initiation, propagation, acceleration, due, past due and fail. The
5 timing is defined as the percentage of the pavement surface life as FIGURE 1 shows. The
6 specific values may vary from section to section, but the overall trends are similar. The figure
7 illustrates the typical progression trend throughout the pavement surface life based on analyses
8 of over 50 years of historical performance data recorded in WSPMS. Also, the deterioration rates
9 rise in each zone as the pavement condition progresses from the initiation zone to the past due
10 zone (1, 7).
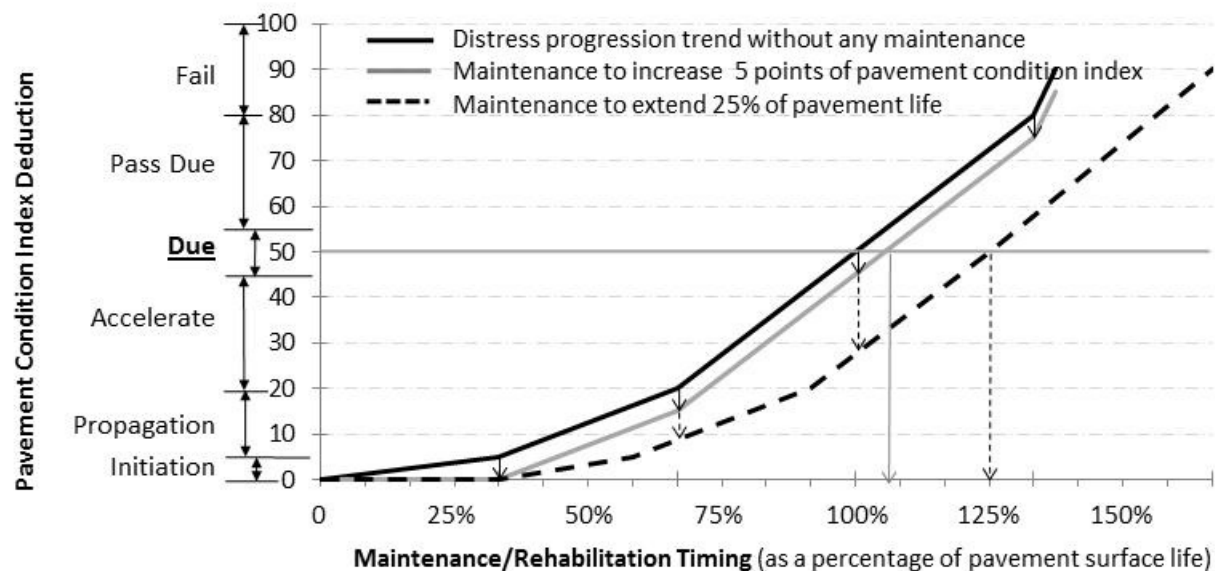
11
12 **FIGURE 1 Deduction points of pavement condition index vs. maintenance/rehabilitation**
13 **timing throughout the pavement surface life.**

14

15 **WSDOT PAVEMENT MAINTENANCE ALTERNATIVES**

16   The decision variables to assess are the maintenance and rehabilitation activities and not
17 simply the commonly used treatments associated with Pavement Preservation (preventive
18 maintenance, routine maintenance, and minor rehabilitation) (8). Both maintenance and
19 rehabilitation activities must be considered in the overall life-cycle cost analysis of the pavement
20 strategy, since the maintenance will affect the timing of more expensive rehabilitation
21 treatments, even though maintenance is typically much lower in cost. Then, the decision variable
22 becomes (1) the selection of one or multiple maintenance treatments, and (2) timing of the
23 maintenance. TABLE 1 summarizes typical unit costs and the expected pavement life extension
24 for WSDOT's typical maintenance treatments. The agency costs may vary due to the location,
25 pavement distress condition, project length and traffic conditions. The costs are the average of
26 WSDOT's maintenance contracts in the last two years (2011 to 2013) which include engineering
27 and traffic control. The life extension is mostly dependent on the timing when the maintenance is
28 performed and the distress condition at that time (1, 9, 10).

TABLE 1 Unit Costs and Expected Pavement Life Extensions for WSDOT's Typical Maintenance Treatments

Pavement Type	Maintenance Treatment	Unit Cost (\$/repaired length)	Life Extension (years)
ACP	Crack sealing	\$0.9 to1.2 / foot	1 to 3
	Patching	\$5 to 10 / square yard	1 to 5
PCCP, un-doweled JPCP	Crack sealing	\$1 to 2 / foot	1 to 4
	Joint sealing	\$1.25 to 2.5 / foot	4 to 7
	Grinding	\$125,000 / lane-mile	8 to 15
	Slab replacement	\$10,000 to 20,000 / slab	5 to 20
	Dowel bar retrofit	\$700,000 / lane-mile	10 to 20
Chip seal	Crack sealing	\$0.9 to 1.2 / foot	1 to 2
	Patching	\$3.5 to 4 / square yard	1 to 3

Pavement Maintenance Strategies

Current budget constraints in Washington State necessitate the development of new strategies with regard to maintenance. In these strategies, pavement rehabilitation funds are being specifically allocated for maintenance activities such as:

1. **<u>Addressing early distress</u>:** For this situation, premature distress may be occurring relatively early in the performance period. This may be due to construction problems, reflection cracking, or other factors, but if those premature distresses are not addressed, then an early rehabilitation may be required which substantially increases the life-cycle costs. It has been recognized that applying preventive maintenance treatments early in a performance period is far more effective than applying it to a pavement in poor condition.

2. **<u>Maintaining sections that are currently due for rehabilitation</u>:** Under the current constrained budget, sometimes, even if the optimum long-term rehabilitation plan for a particular section of roadway calls for a pavement rehabilitation project, there may not be funds available to program the project. This situation has resulted in the development of maintenance strategies for the purpose of delaying or avoiding pavement rehabilitation.

3. **<u>Holding the past-due sections together until funds are available for rehabilitation</u>:** When the funding is further constrained, even the past-due sections cannot be funded for rehabilitation. Then, maintenance has to be applied to hold the pavement together until the rehabilitation can be performed. It is recognized that this is not an efficient or effective long-term use for funds, but it is sometimes necessary for short-term situations.

WSDOT will continue to plan the best strategies possible for the preservation of the road network. It is apparent, however, that continued under-funding will generate large backlogs of rehabilitation projects which eventually will reduce the quality of the road system and lead to excessive long-term costs (both for the agency and the users).

Pavement Maintenance Timing and Pavement Condition Zones

The concept of the different pavement maintenance alternatives and when they are applicable are illustrated in TABLE 2. As the pavement ages, maintenance alternatives are appropriate.

1 Eventually the pavement will deteriorate to the point where maintenance treatments are not
2 sufficient, and the pavement condition will worsen until major rehabilitation is required (*9*, *10*).

3 **TABLE 2 Six Pavement Condition Zones and Corresponding Maintenance Timing**

Surface Type	Condition Zones	Condition Index Deduction	Timing*	Maintenance Treatment	Risk of Catastrophic Failure
ACP	Initiation	<5	<33	Crack sealing with or without minor patching, partial chip seal overlay	None
	Propagation	5 to 20	33 to 67	Crack sealing with or without patching, partial chip seal overlay	Low
	Acceleration	20 to 50	67 to 100	Crack sealing with more patching, partial chip seal overlay, partial HMA overlay	Moderate
	Due	45 to 55	≈100	Aggressive sealing and patching, partial HMA overlay	High
	Past Due	55 to 80	100 to 133	Partial HMA overlay, patching	Extreme
	Fail	80 to 100	>133	Not recommended	Extreme
PCCP, Undowled JPCP	Initiation	<5	<33	DBR	None
	Propagation	5 to 20	33 to 67	Grinding with or without selective slab replacement, DBR	Low
	Acceleration	20 to 50	67 to 100	Grinding with more slab replacement, DBR	Moderate
	Due	45 to 55	≈100	Grinding, aggressive slab replacement, partial reconstruction	High
	Past Due	55 to 80	100 to 133	Grinding, aggressive slab replacement, partial reconstruction	Extreme
	Fail	80 to 100	>133	Not recommended	Extreme
Chip seal	Initiation	<5	<33	Crack sealing	None
	Propagation	5 to 20	33 to 67	Crack sealing with or without patching	Low
	Acceleration	20 to 50	67 to 100	Crack sealing with more patching, partial chip seal overlay	Moderate
	Due	45 to 55	≈100	Long wheel-path patching, partial chip seal overlay	High
	Past Due	55 to 75	100 to 133	Partial chip seal overlay	Extreme
	Fail	80 to 100	>133	Not recommended	Extreme

4 *Notes: The timing is defined as the percentage of the pavement surface life.*

5   As TABLE 2 shows, late in the age of the pavement structure is the point when risk of
6 catastrophic failure is higher, it is important to closely monitor the condition of the pavement
7 structure. Sometimes this can be a number of years, and it is advantageous to delay the large
8 capital cost of rehabilitation or reconstruction as long as possible. If needed repairs are deferred
9 too long, then the costs to rebuild the pavement structure are much higher, and the opportunity to
10 capture the lowest life-cycle cost is lost. There higher costs then result in fewer miles being
11 rehabilitated, causing more pavements to deteriorate, and resulting in a downward spiral of
12 decreasing road quality and increasing pavement costs.

13

14 **PAVEMENT MAINTENANCE** - LOWERING COSTS BY EXTENDING PAVEMENT LIFE

15 A life-cycle cost analysis is a key methodology for evaluating alternative pavement rehabilitation

1   strategies (*11*, *12*). In most life-cycle cost evaluations, the maintenance cost is small in
2   comparison to rehabilitation or user costs, so it seldom controls the long-term costs. However, if
3   the effect of maintenance on pavement service life is taken into consideration, then the effect of
4   maintenance on life-cycle costs becomes significant.

5

6   **Equivalent Uniform Annual Cost (EUAC)**

7   The Equivalent Uniform Annual Cost (EUAC) can be used to compare the long-term costs of
8   one road segment versus another, and to determine the best management practices relative to
9   efficient pavement management. It is defined by the Equation 1 for one or more pavement
10   performance periods, expressed in terms of dollars per lane-mile per year (*13*).

$$\text{EUAC} = \frac{\text{NPV} * i}{1 - 1/(1 + i)^n} \qquad \text{Equation 1}$$

11   Where,
12   EUAC   Equivalent Uniform Annual Cost, in dollars per lane-mile per year ($/LMY);
13   NPV   Net present value,

$$\text{NPV} = \text{Rehabilitation Cost} + \frac{\text{Maintenance Cost}}{(1 + i)^k} \qquad \text{Equation 2}$$

14   *i*   Discount rate, assuming *4%*;
15   *n*   Service life of the rehabilitation and maintenance, in years;
16   *k*   Year that maintenance will be performed.

17   The effectiveness of a rehabilitation or maintenance treatment can be evaluated on the on
18   the basis of long-term annual cost considering the difference in pavement life and costs. For
19   example, if an asphalt overlay costs $250,000 per lane-mile and is expected to last 12 years , but
20   is extended to 13 years, then, the annual cost is reduced from $26,638 to $25,036, a 6% drop. As
21   long as the maintenance does not cost more than $1,602 per lane-mile per year, it is cost
22   effective. This concept of percent change in EUAC as a function of one year change in service
23   life for asphalt concrete pavements, concrete pavements and chip seal surfaced pavements is
24   illustrated in FIGURE 2. The graph shows that EUAC savings range up to 23% per year of life
25   extension. The EUAC savings vary for different surface types, but the trends are similar.
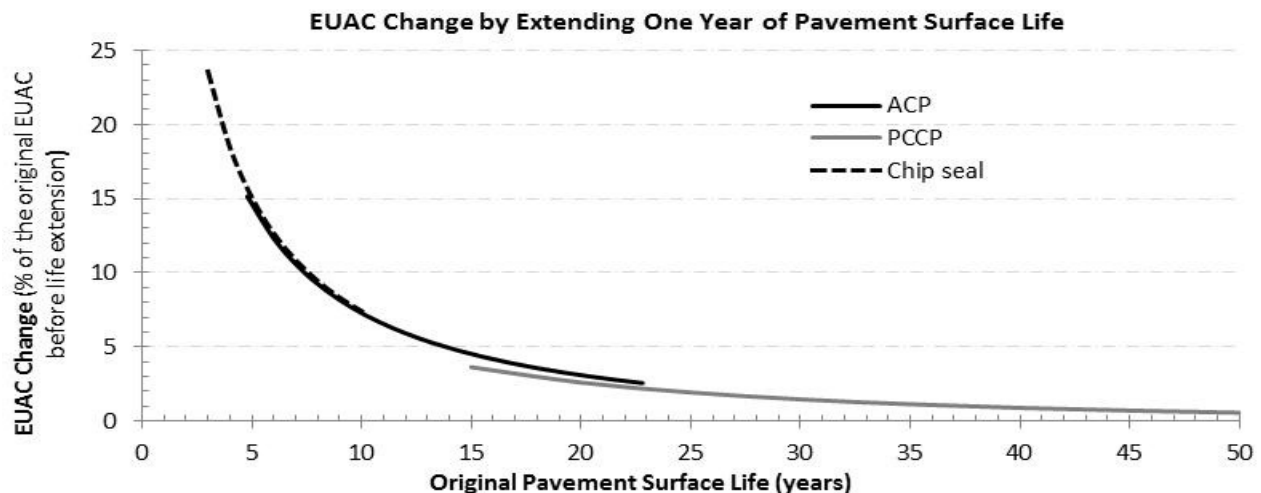
26
27   **FIGURE 2 Percent change in EUAC as function of one-year change in surface life.**

Benefit-Cost Ratio

The net EUAC benefits are an appropriate way to compare different pavement strategies by providing the lowest life-cycle cost. However, if funds are not available to implement the lowest cost strategy, then sub-optimum strategies may be selected. When this occurs, it is useful to evaluate which sub-optimum strategies are the most cost efficient. This type of evaluation is analyzed using a benefit-cost ratio which can be expressed as a ratio of the EUAC benefit and EUAC cost of maintenance which is applied k years after the rehabilitation.

$$\text{Benefit/Cost Ratio} = \frac{\text{EUAC Benefit}}{\text{EUAC of Maintenance Cost}} \qquad \text{Equation 3}$$

Where,

$$\text{EUAC Benefit} = \frac{\text{Rehabilitation Cost}*i}{1-1/(1+i)^n} - \frac{\left(\text{Rehabilitation Cost}+\frac{\text{Maintenance Cost}}{(1+i)^k}\right)*i}{1-1/(1+i)^{n+k}}$$

$$\text{EUAC of Maintenance Cost} = \frac{\text{Maintenance Cost}/(1+i)^k*i}{1-1/(1+i)^{n+k}}$$

To evaluate the cost effectiveness of maintenance activities at different times in the service life of a pavement structure, a range of activities, costs, and timeframes was analyzed by determining the life-cycle EUAC for each scenario. These scenarios were then compared with the baseline of a rehabilitation EUAC calculated based on the average unit rehabilitation cost and average surface life without any maintenance treatments. These results are illustrated in TABLE 3. The costs and average life are the average of 2013 WSPMS data (*1*).

TABLE 3 EUAC of WSDOT's Typical Rehabilitation Methods

Pavement Type	Typical Rehabilitation Method	Unit Rehabilitation Cost *($/lane-mile)*	Surface Life* *(year)*	EUAC *($/lane-mile-year)*
ACP	HMA overlay	250,000	12	26,638
PCCP	Reconstruction	2,500,000	35	133,943
Chip seal	Chip seal	40,000	6	7,630

Notes: Life without any maintenance, and 35-years for un-doweled JPCP.

Three scenarios were developed by varying the following factors at 33% (one third), 67% (two third) and 100% of the pavement surface life (Scenario 1 and 2 are shown in FIGURE 1):

- ***Scenario 1: increasing 5 points of the pavement condition index***. The same amount of distress is repaired at the different timing, as percentage of the pavement surface life. The unit maintenance cost and the extended life vary, which leads to various effectiveness.
- ***Scenario 2: extending pavement life by 25%***. On average, three years for ACP, 12 years for PCCP and 1.5 years for chip seal, except that newer PCCP (< 12 years) cannot be extended for 9 years with reasonable repairs due to the special physical properties of concrete. The required maintenance methods and costs vary due to the changing pavement distress conditions along the surface life.
- ***Scenario 3: spending same amount of maintenance funding at different timing***. With the same amount of funding ($5,000 for ACP, $500,000 for PCCP and $2,000 for chip seals), the pavement conditions and life extension may vary due to the different timing.

Specific one or more maintenance treatments (listed in TABLE 2) may be selected according to engineer judgments based on the pavement distress condition, the timing and the

1 available funding. The TABLE 4-a, 4-b and 4-c provides a comparison of benefit-cost ratios for
2 the above scenarios for WSDOT typical pavements: average surface life of 12 years, 35 years
3 and 6 years for ACP, PCCP and chip seal without any maintenance treatment.

4 **TABLE 4-a Cost Effectiveness Evaluation for Scenario 1: Increasing 5 Point of the**
5 **Pavement Index**

Pavement Type	Timing*	Maint. Year	Maint. Cost ($/lane-mile)	Extended Life (year)	Net Benefit (ΔEUAC)	Benefit-cost Ratio
ACP	33%	4	5,000	2	2,497	6.2
	67%	8	7,500	1	851	1.6
	100%	12	10,000	0.5	-198	-0.3
PCCP	33%	12	-	-	-	-
	33%	23	150,000	3	-2,881	-0.9
	100%	35	200,000	3	-5,463	-2.1
Chip seal	33%	2	2,000	1.5	1,038	3.6
	67%	4	3,000	1.0	466	1.1
	100%	6	4,000	0.5	-191	-0.3

6 *Notes: The timing is defined as the percentage of the pavement surface life.*

7 **TABLE 4-b Cost Effectiveness Evaluation for Scenario 2: Extending 25% of Surface Life**

Pavement Type	Timing	Maint. Year	Maint. Cost ($/lane-mile)	Extended Life (year)	Net Benefit (ΔEUAC)	Benefit-cost Ratio
ACP	33%*	4	-	-	-	-
	67%	8	20,000	3	2,354	1.8
	100%	12	40,000	3	555	0.2
PCCP	33%*	12	-	-	-	-
	67%	23	500,000	9	-12,050	-1.2
	100%	35	1,000,000	9	-36,383	-3.0
Chip seal	33%	2	2,000	1.5	1,038	3.6
	67%	4	4,000	1.5	724	1.3
	100%	6	8,000	1.5	96	0.1

8 *Notes: The WSDOT typical maintenance treatments can seldom extend 25% of pavement surface life,*
9 *since the pavements are relatively new, and do not have much distress to be fixed.*

10 **TABLE 4-c Cost Effectiveness Evaluation for Scenario 3: Spending Same Amount of**
11 **Maintenance Funding**

| Pavement Type	Timing	Maint. Year	Maint. Cost ($/lane-mile)	Extended Life (year)	Net Benefit (ΔEUAC)	Benefit-cost Ratio
ACP	33%	4	5,000	2	2,497	6.2
	67%	8	5,000	0.75	717	1.9
	100%	12	5,000	0.25	-99	-0.30
PCCP	33%	12	-	-	-	-
	67%	23	500,000	9	-12,050	-1.2
	100%	35	500,000	5	-17,627	-2.8
Chip seal	33%	2	2,000	1.5	1,038	3.6
	67%	4	2,000	0.50	165	0.5
	100%	6	2,000	0.25	-97	-0.3

1   The costs and life extension are estimated based on WSDOT's historical maintenance
2 practices and contracts. Treatments with relatively low benefits may be selected when budget
3 limitations do not allow spending the funds for the strategy with the higher net benefits. The
4 tables indicate that substantial cost savings can be realized with preservation treatment scenarios
5 applied early in the distress cycle. The ratio ranged up to 6.2. For ACP and chip seal, the best
6 time for maintenance is at earlier pavement life resulting in longer life extension.

7   The treatments with negative net benefit would be cases where the activity would be not
8 cost effective, and the savings would not justify the expenditures for the maintenance activities.
9 For example, PCCP maintenance treatments all have negative benefit and benefit-cost ratio that
10 indicates the corresponding treatments are not cost effective. However, the required PCCP
11 reconstruction is expensive and generally beyond the WSDOT's funding availability, therefore,
12 maintenance treatments have to be chosen to extend the pavement life with insufficient current
13 cash flow.
14

15 **Breakeven Analysis to Evaluate Maintenance Tradeoffs**

16 WSDOT is facing accelerating pavement rehabilitation backlogs, and more due and past due
17 sections cannot be rehabilitated on time. Even though maintaining pavement at an earlier age
18 may generate more financial savings, the continuously constrained budget may only allow more
19 maintenance applied to the due section.

20   FIGURE3-a illustrates the net EUAC benefits for maintenance methods (TABLE 3)
21 applied at the due year as a function of extended surface life. The net EUAC benefits are
22 expressed in percentage of the original EUAC of rehabilitation without any maintenance, and the
23 extended surface life is expressed as a fraction of the original surface life. The results indicate
24 that maintenance applied to chip seal pavements is more cost effective than ACP and PCCP as
25 percent of the original EUAC without maintenance. The benefit of PCCP maintenance is the
26 lowest among the three pavement types. FIGURE3-b shows the "breakeven point", which is the
27 percent increase in surface life that will pay for the maintenance activity cost applied at the due
28 year.
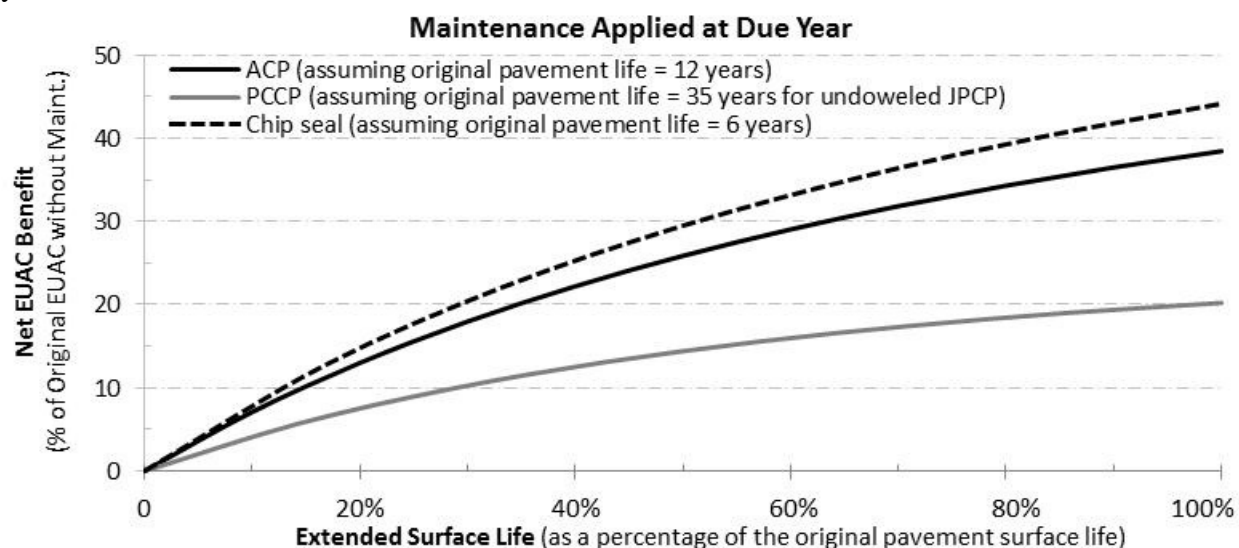
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30 **FIGURE 3-a Net EUAC benefits as a function of surface life extension for corresponding**
31 **maintenance/rehabilitation treatments applied at the due year.**
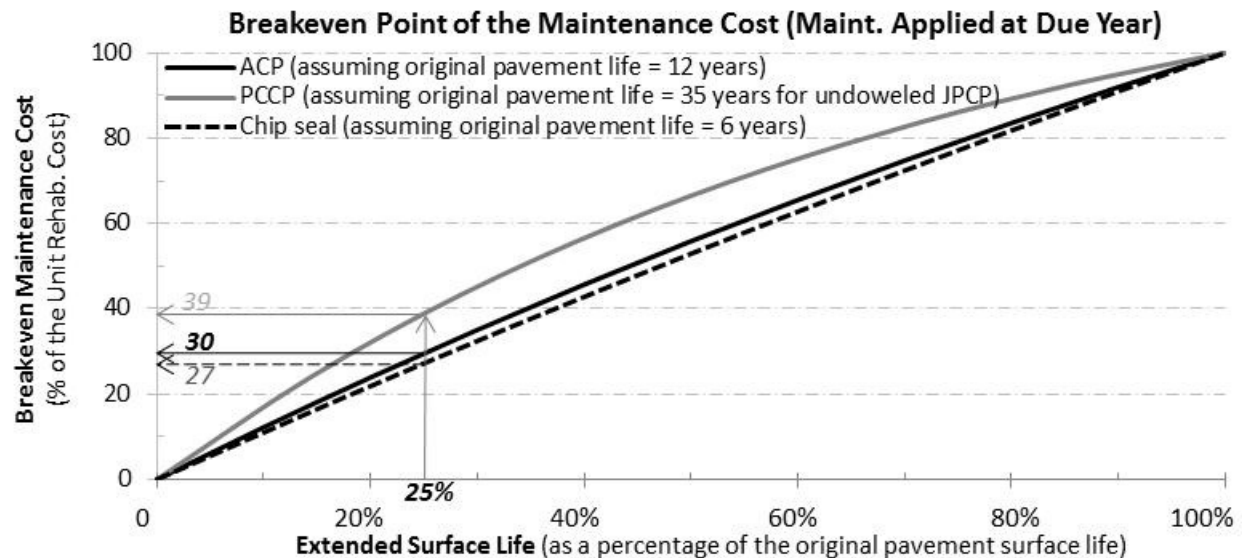
1
2 **FIGURE 3-b Breakeven point of maintenance cost as a function of surface life extension for**
3 **corresponding maintenance/rehabilitation treatments applied at the due year.**

4   For example, to determine how much could have been spent on maintenance on ACP and
5 still break even with the annual cost savings resulting from an extension of 25% pavement
6 surface life, 12 years to 15 years, how much additional maintenance can be spent to break even
7 with an equivalent annual cost with $250,000 for initial rehabilitation of HMA overlay, $26,638
8 per year annual cost? The tradeoff evaluation is shown in FIGURE3-b. Using discount rate of
9 4%, and the maintenance and extended pavement life will reduce the EUAC to $22,485 per year.
10 The breakeven would simply be the total EUAC saving over the 15 years indicating that $74,000
11 could be spent on maintenance at the due year and break even with the reduced annual cost
12 resulting from an additional 3 years of life.

13   Continuing with the previous example of extending 25% of the surface life, the
14 breakeven point is 27% additional cost for chip seal to extend 1.5 years. In other words, any
15 maintenance costs less than 27% (of $40,000/lane-mile chip seal overlay cost) would bring
16 benefit to the LCCA of the section. The breakpoint is 39% (of $2,500,000/lane-mile of
17 reconstruction) for PCCP to extend 9 years of surface life. Even though the results illustrated in
18 the graphs are only from one specific set of example scenarios, in general, they indicate that the
19 low costs of maintenance are easily paid off for ACP and chip seal with increases in pavement
20 life.

21

22 **MAINTENANCE EFFECTIVENESS FOR WSDOT'S HIGHWAY NETWORK**

23 The feasible pavement maintenance alternatives can be one, or a combination of methods at
24 different times based on engineering judgment, pavement conditions and funding availability. To
25 evaluate the long term cost-effectiveness of different maintenance approaches, three maintenance
26 and rehabilitation alternatives were analyzed for each individual preservation unit throughout the
27 WSDOT highway network. WSPMS estimates surface life based on the previous resurface year
28 and the estimated due year. Therefore, the year to apply maintenance treatment may vary, even
29 for the same surface type, since the estimated surface life varies. In calculating the Due Year, the
30 historical maintenance activities and the corresponding extended life is taken into consideration.

The EUAC and benefit-cost ratio analysis indicate that applying maintenance treatments earlier with a sufficient repair is the most effective and result in the lowest life cycle cost. As FIGURE 4-a shows the current WSDOT situation of (1) accelerating backlogs (past-due and fail zones); (2) 38% of PCCP are due and require expensive reconstruction; and (3) further constrained budget in the next 6 years. To illustrate the impacts of different maintenance strategies on a network level, three preservation alternatives are compared:

- **Alternative #1:** Assuming only the major rehabilitation methods (as listed in TABLE 3) are applied to the network whenever the section is due, but no maintenance is applied. The cost for the 0 to 33% of surface life is extremely high because all previous backlogs will be treated. And, for the past-due and failed sections, pre-leveling, extra preparation and repairs or reconstruction may be necessary.

- **Alternative #2:** The maintenance is applied at the best timing for the most cost-effective result for acceptable condition throughout the whole surface life. The optimal timing is to address most distresses as early as possible. However, it generates high cost for 0 to 33% of surface life also, since most maintenance is applied and the backlogs are all fixed during this period of time.

- **Alternative #3:** Aggressive maintenance is selected to postpone the pavement rehabilitation expenditures as late as possible due to the constrained budget. The effort is focused on holding the pavement together and preventing further damages. The overall cost might be low, but the risk of severe failure is high, and major rehabilitation or reconstruction backlogs will develop which all eventually need to be completed when funding becomes available. So, the short-term reduction in costs is more than offset by much higher future costs due to expensive pavement condition backlogs.

The summary of the three preservation alternatives for WSDOT highway networks are illustrated in FIGURE 4-b. Overall, Alternate #1 is the most expensive and would preserve the pavement in the best condition. Alternate #2 provides the best benefit-cost factor and achieves satisfactory road condition. Alternate #3 costs the least within the time period because expenditures are delayed, but it has the highest risk of catastrophic failure. No rehabilitation backlog is generated by Alternatives #1 and #2, but Alternative #3 generates enormous backlogs in the end. Ultimately, roads under Alternative #3 lost the opportunity to capture the low life-cycle cost, and result in requiring much higher cost for major rehabilitation or complete reconstruction.
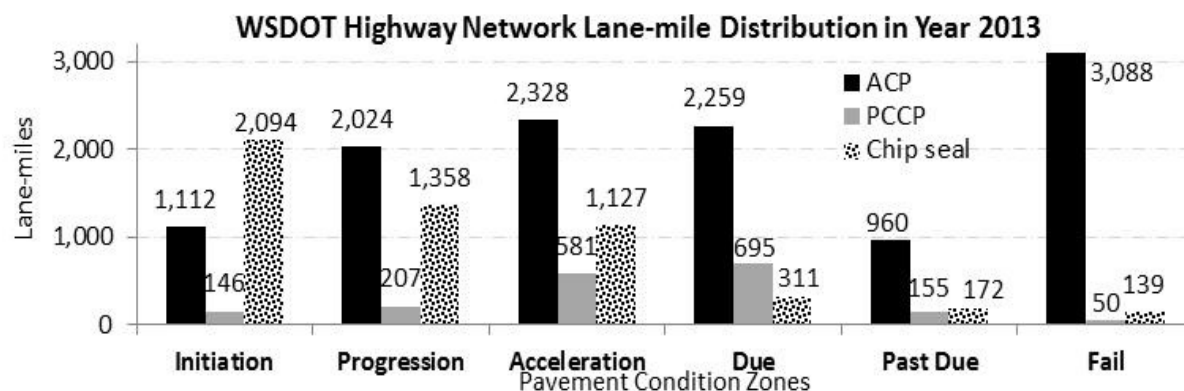
FIGURE 4-a Lane-mile distribution of each pavement condition zones for WSDOT highway network of ACP, PCCP and chip seals in year 2013.

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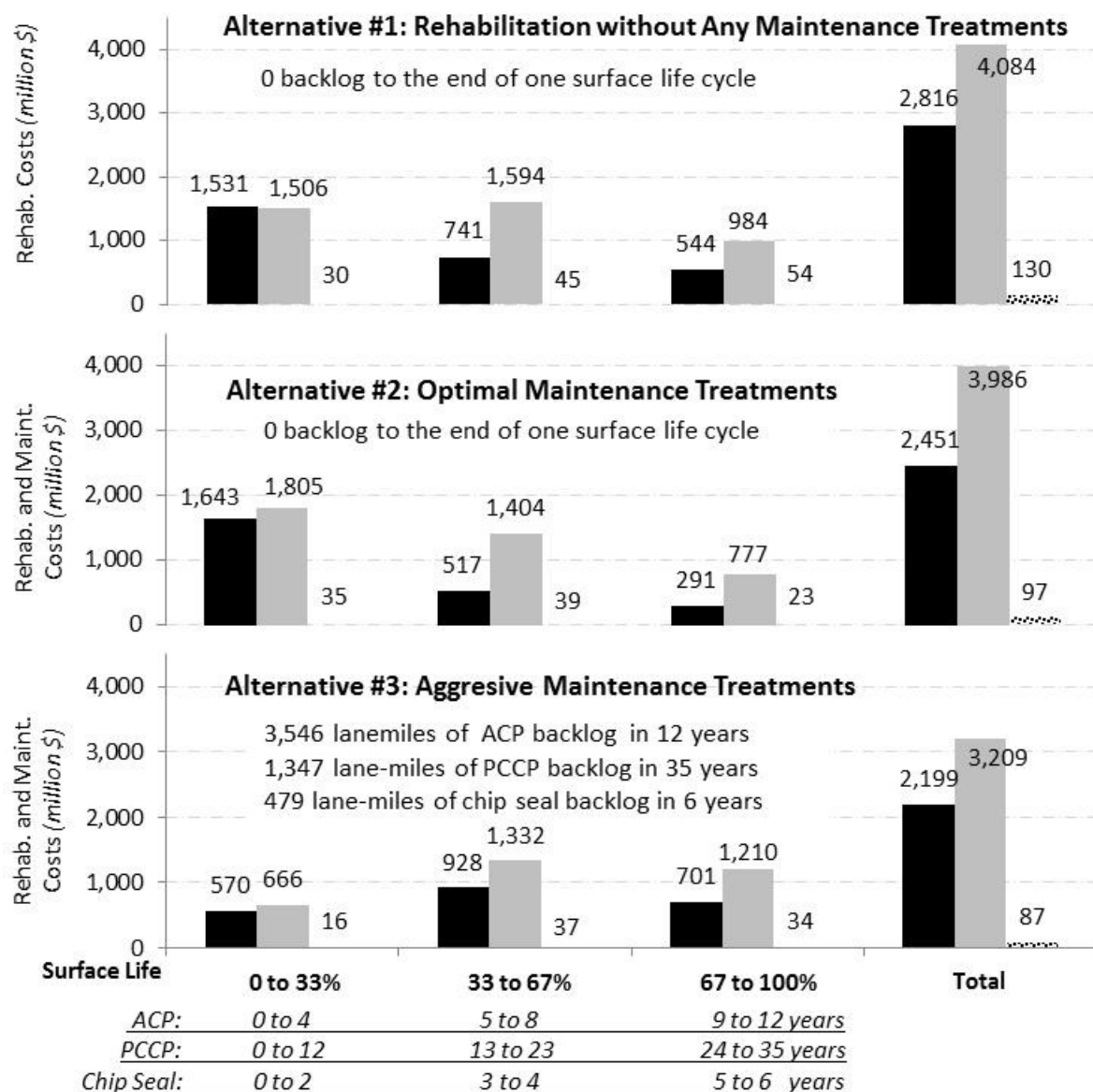
5 **FIGURE 4-b Estimated prospective costs of the three preservation alternatives throughout**
6 **one average surface life cycle of ACP, PCCP and chip seal for WSDOT highway network.**

7   The estimates are developed based on assumptions and are therefore only
8 approximations. The proposed alternatives will be refined with more analysis of reducing overall
9 expenditures and providing better pavement performance. If used to plan specific projects, these
10 results may be changed based on site conditions and further investigation.

11

12 **FUTURE RESEARCH ON PERFORMANCE OF MAINTENANCE TREATMENTS**

13 WSDOT started in 2012 a research study in order to better understand the effect of maintenance
14 treatments on pavement performance. A simplified approach was taken, given the difficulties of
15 a large designed experiment. The basic approach is to examine several treatments at a single

location using short (quarter mile) test sections. In this way, several treatments can be viewed adjacent to each other on a road with relatively uniform pavement and traffic conditions. These treatments are then replicated at other locations across the state to evaluate if performance differences exist with different climates and traffic conditions. This research study will expand in scope to incorporate more locations and treatment types in the next 2-3 years, and then performance will be closely monitored for several years to quantify the effects of pavement maintenance.

CONCLUSIONS

This study evaluated the effectiveness of maintenance alternatives, introduced the breakeven point to balance the extended life and added cost, improved the procedures for analyzing maintenance tradeoffs, and compared possible maintenance scenarios and strategic plans for WSDOT highway network. Findings that may benefit others are:

1. The continued under-funding of pavement rehabilitation is generating large backlogs of projects which eventually will reduce the quality of the road system and lead to excessive long-term costs. Additional funding for pavement preservation is necessary to minimize the more costly alternative of replacing pavement.

2. The net EUAC benefits and benefit-cost ratio is a way to compare different pavement strategies and life-cycle costs.

3. Alternative maintenance strategies are developed corresponding to constrained budgets.

4. It has been recognized that applying maintenance treatments early in a performance period is far more effective than applying it to a pavement in poor condition.

5. The plan of rehabilitation with well-timed maintenance generates the highest benefit-cost factor. Both maintenance and rehabilitation activities must be considered in the overall life-cycle cost analysis of the pavement strategy, since the maintenance will affect the timing of more expensive rehabilitation treatments, even though maintenance is typically much lower in cost.

6. The analysis of WSPMS performance data provides a quantitative understanding of the WSDOT pavement network. It clearly shows the need for pavement rehabilitation and maintenance throughout the surface life cycle for ACP, PCCP and chip seal networks.

1 **DISCLAIMER**

2 This paper contains the opinions and viewpoints of the authors alone, and does not constitute a

3 policy or standard of the Washington State Department of Transportation.

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